A soluble fibre gel produced from rice bran and barley flour as a fat replacer in Asian foods

George E. Inglett,[1] Craig J. Carriere,[1]* Saipin Maneepun[2] & Patcharee Tungtrakul[2]

1 Cereal Products and Food Science Research Unit, National Center for Agricultural Utilization Research, ARS, USDA, Peoria, IL 61604, USA
2 Institute of Food Research and Product Development, Kasetsart University, Bangkok 10903, Thailand

(Received 10 September 2001; Accepted in revised form 28 April 2003)

Summary A hydrocolloidal fibre composite made from rice bran and barley flour, called Ricetrim, was found to have similar rheological properties to coconut cream. Coconut cream displayed a very narrow region of linear viscoelastic behaviour, both above and below strain values of 0.1%, the oscillatory shear modulus dropped sharply with increasing strain, indicating non-linear viscoelastic behaviour. This region of linear viscoelastic behaviour extended to strains of 10%. When Ricetrim was substituted for coconut cream in Thai foods, it was found to produce acceptable products, but with lower saturated fat contents. Cookies, pumpkin pudding, layer cake, dip for pot crust, taro custard and sauté chicken curry were produced with fat contents reduced by 47.8, 94.3, 59.8, 75.3, 61.3 and 60.6%, respectively. Some differences in flavour and texture were observed at the higher levels of substitution, but these differences appeared to present only small changes in the overall score of general acceptability, or suitability, of the fibre gel foods. Scanning electron micrographs of the pumpkin pudding revealed only small changes in their surfaces with Ricetrim addition, even at higher levels of substitution.

Keywords Coconut cream, dynamic rheological properties, proximate composition, saturated fat, scanning electron microscopy, sensory evaluation.

Introduction

Dietary fat reduction and appropriate caloric intake are considered important factors in maintaining good health. People with high blood cholesterol levels are considered to be at risk of heart disease. Cereal grain products have been recognized to be effective in lowering serum cholesterol (deGroot *et al*., 1963; Inglett & Newman, 1994; Behall *et al*., 1997). A recent analysis of several studies has shown the consistent efficacy of oats as a hypocholesterolemic agent in humans (Ripsin *et al*., 1992). The Food and Drug Administration (1997a,b) has recently allowed rolled oats, oat flour and oat bran to claim health benefits provided that they are used to give at least 3 g of soluble fibre [(1-3)(1-4)-beta-D-glucan] per day and used as a part of a low-saturated fat, low-cholesterol diet. As the soluble fibre, β-glucan, from oats and barley is recognized for its hypocholesterolemic value, soluble fibre products, such as Oatrim, have been widely used as fat replacement ingredients (Inglett, 1991, 1992, 1993; Inglett & Grisamore, 1991). More recent activities are based on using biologically active soluble fibres as nutraceuticals and food supplements (Inglett, 1999). This study was made in order to determine the influence of using soluble fibre gels from Ricetrim (a composite of co-processed rice bran and barley flour) on the nutritional value of Thai

Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable. All programs and services of the US Department of Agriculture are offered on a nondiscriminatory basis without regard to race, colour, national origin, religion, sex, age, marital status, or handicap.

*Correspondent: Fax: +1 309 681 6685;
e-mail: carriecj@ncaur.usda.gov

foods that are made with substantial amounts of butter and coconut fat. For this study, it was also necessary to determine whether Ricetrim had similar rheological and sensory properties as coconut cream. Coconut cream is the principal source of saturated fat in the Thai diet and is partially responsible for increases in hypercholesterolemic conditions in Southeastern Asia. These conditions also exist in the Western cultures that consume diets rich in saturated fats.

Materials and method

The composite of soluble fibres, Ricetrim, was obtained by co-processing rice bran and barley flour by means of a patented method (Inglett, 2000). A 10% fibre gel was prepared by blending weights of 10% fibre with 90% water, heating and boiling for 2 min, then cooling to room temperature and allowing the material to gel in a refrigerator overnight. Six Thai foods commonly consumed in South-east Asia, all containing more than 25% butter or coconut cream, were examined to evaluate the efficacy of using Ricetrim to decrease their saturated fat contents, by using it as a replacer for coconut cream and butter.

The 10% fibre gel was substituted on a weight for weight basis for 40, 60 and 80% of the butter/shortening in cookies. Coconut cream, which is used to prepare layer cake, fried pot crust and dip, taro custard and sauté chicken curry, was replaced with 10% fibre gel at 40, 60 and 80% of the coconut cream by weight; for pumpkin pudding the 10% fibre gel was substituted for 50, 75 and 100% of the coconut cream by weight.

A commercial coconut cream sample containing 69% fat by weight (D'Best Coconut Cream Kakang Gata; Simplex International, South San Francisco, CA, USA) was purchased and used as a reference for the rheological studies. The sample was used as received without additional modification.

Thai food formulations

The fats (butter and coconut cream) in the various products were substituted by various amounts of Ricetrim soluble fibre gel as described for Oatrim and Nutrim in earlier studies (Inglett *et al.*, 1994, 2000; Maneepun *et al.*, 1998a,b). These Thai foods were selected to show the versatility of the fibre gel as a replacement for coconut cream. The Thai foods were prepared as follows:

Cookies
Ingredients: 155 g all purpose flour, 45 g cake flour, 90 g butter, 38 g shortening, one teaspoon baking soda, 50 g egg, 110 g sugar and one teaspoon vanilla extract. *Preparation*: the sifted flour was blended with baking soda before mixing with butter, shortening, and sugar until creamy. The egg and vanilla extract was added with continued mixing for 1 min. The flour was added, with spatula blending, before the mixture was poured onto a baking tray and baked at 177 °C for 30 min. The 10% Ricetrim fibre gel was substituted for 40, 60 and 80% of the butter-shortening in the cookie mixture as follows: 90 g butter and 38 g shortening (control); 51.2 g fibre gel, 54 g butter and 22.8 g shortening (40% substitution); 76.8 g fibre gel, 36 g butter and 15.2 g shortening (60% substitution); 102.4 g fibre gel, 18 g butter and 7.6 g shortening (80% substitution).

Pumpkin pudding
Ingredients: 400 g pumpkin, 100 g rice flour, 70 g arrowroot flour, 200 g sugar, 280 g coconut cream, 4 g salt and 50 g grated coconut. *Preparation*: pumpkin was sliced into long 1-in thick pieces, steamed until soft and mashed thoroughly. Pumpkin was mixed with rice and arrowroot flours followed by the sugar and salt. The mixture was mixed with coconut cream or the fibre gel in the following proportions: 280 g coconut cream (control); 140 g coconut cream (140 g fibre gel) (50%); 77.5 g coconut cream (202.5 g fibre gel) (75%); and (280 g fibre gel) (100%). The mixture was poured onto a baking pan and grated coconut sprinkled on the surface before steaming for 30 min.

Layer cake
Ingredients: 75 g tapioca flour, 35 g arrowroot flour, 5 g rice flour, 250 g coconut cream, 150 g sugar, 60 g water and 10 g pandan leaf extract. *Preparation*: sugar was boiled with water to make a syrup before mixing it in a bowl with the rice, tapioca and arrowroot flours. The mixture was mixed well with coconut cream or the fibre gel in the following proportions: 1000 g coconut cream

(control); 600 g coconut cream (400 g fibre gel) (40%); 400 g coconut cream (600 g fibre gel) (60%); and 200 g coconut cream (800 g fibre gel) (80%). The mixture was divided equally into two portions. For the first portion, pandan leaf extract was added and mixed thoroughly before pouring the first layer (white) onto a baking pan and steaming until cooked. The second portion was blended with a green colouring and poured on top of the baked white layer and then steamed until cooked. Alternate white and green layers were made to the desired level of the cake, the last layer being green.

Fried pot crust and dip

Ingredients for dip: 300 g ground chicken, 80 g ground roasted coconut, 700 g coconut cream, 85 g shallot, 200 g sugar, 20 g salt, 10 g coriander root, 6 g pepper, 8 g dried chilli, 8.3 g coriander and 200 g water. *Preparation*: coriander root, pepper and chilli were ground well in a mortar. In a separate container, the coconut cream and fibre gel, in the following proportions, were boiled: 700 g coconut cream, (control); 420 g coconut cream (280 g fibre gel) (40%); 280 g coconut cream (420 g fibre gel) (60%); and 140 g coconut cream (560 g fibre gel) (80%). The spice blend was added to the boiled material, stirred well before the ground chicken, sugar, salt added and stirred. The mixture was heated to boiling and then the peanuts and shallot were added. After the mixture was removed from the heat, it was served with fried pot crust or crisp fried bread or Melba toast that had been fried over medium heat until golden brown on both sides.

Taro custard

Ingredients: 500 g egg, 575 g coconut cream, 115 g sugar, 315 g coconut sugar, 250 g chopped taro and 50 g pandan leaf extract. *Preparation*: egg, sugar, coconut sugar and pandan leaf extract were blended for 4 min and coconut cream added in the following proportions: 575 g coconut cream (control); 345 g coconut cream (230 g fibre gel) (40%); 230 g coconut cream (345 g fibre gel) (60%); and 115 g coconut cream (460 g fibre gel) (80%). The mixture was poured through cheesecloth and collected on a tray before sprinkling with chopped taro and steaming for 25 min.

Sauté chicken curry

Ingredients: 750 g sliced chicken, 750 g coconut cream, 150 g curry paste, 60 g cane sugar, 50 g fish sauce, 50 g basil leaves and 4 g sliced kaffir lime leaves. *Preparation*: Fry chicken was cooked and removed from the pan. In the pan the spice mixture was heated with the coconut cream in the following proportions: 750 g coconut cream (control); 450 g coconut cream (300 g fibre gel) (40%); 300 g coconut cream (450 g fibre gel) (60%); and 150 g coconut cream (600 g fibre gel) (80%). The chicken, kaffir lime leaves, sugar and fish sauce were added to this mixture, and allowed to simmer over low heat until the curry was thick before the basil leaves were added.

Food product evaluation

A sensory panel of twenty-five trained members evaluated the Thai foods for the following characteristics: colour, appearance, odour, taste and texture using a 1-9 hedonic scale (Inglett *et al.*, 2000), as follows: like extremely (9), like very much (8), like moderately (7), like slightly (6), neither like nor dislike (5), dislike slightly (4), dislike moderately (3), dislike very much (2), and dislike extremely (1). Significant differences (Irristat version 90-1, Department of Statistics, International Rice Research Institute, Los Banos, Laguna, Philippines) were determined by ANOVA and the Duncan multiple range test. Substituted Thai foods with acceptability scores higher than 6 were analysed for proximate composition and saturated fat (Jham *et al.*, 1992; Association of Official Analytical Chemists, 1998).

Rheological measurements

Ricetrim suspensions were produced at a concentration of 10% by weight in de-ionized water. The solid Ricetrim product was initially slurried in de-ionized water and then introduced into a colloidal mill (Polytron PT6000; Kinematica GmbH, Kriens-Luzen, Switzerland) and sheared at 2000 r.p.m. for 5 min to ensure through suspension of the material. The sample was allowed to cool from 100 °C to room temperature and the resulting suspension was used in the rheological experiments. New samples were produced daily to avoid any possible problems with sample degradation.

Dynamic rheological properties were measured using a CarriMed^{TM} CSL^2 500 (Dorking, UK) controlled stress rheometer with a cone-and-plate fixture. All the rheological studies were done using a 6-cm diameter plate and a 4° cone. The rheometer is capable of measuring torques from 2 to 500 000 Nm. The temperature of the sample was controlled using a Peltier plate, which enabled the chamber of the viscometer to be controlled to within ± 0.1 °C. The transition from linear to non-linear viscoelastic behaviour for each of the materials was investigated using a stress sweep experiment at a fixed frequency of 1 s^{-1}. The stress level was varied from 0.1 to 20 Pa and the value of the oscillatory shear storage modulus, $G'(\omega)$, was measured at each stress level. The steady-state shear experiments were done by subjecting each of the materials to shear rates of 0.2, 1, 10, and 100 s^{-1}, applied for 120 s. The shear stress growth function, $\eta^+(t, \dot{\gamma})$, was measured as a function of time at each applied shear rate, $\dot{\gamma}$. Thixotropic loop experiments were conducted and the shear viscosity, $\eta(\dot{\gamma})$, was measured as a function of applied shear rate. The first upward cycle of the loop was over a shear rate range of 0.8–250 s^{-1} followed immediately by a downward cycle from 250–0.8 s^{-1}. The upward and downward cycles of the loop were kept equal with a total time of 4 min per loop. Fresh samples of the Ricetrim suspension were used for each of the experiments. All the rheological experiments reported herein were done at 25 °C. The experimental data were analysed using TA DATA rheological software and plotted using Wavemetrics IGOR PRO 3.15 software (Wavemetrics Incorporated, Lake Oswego, OR, USA) on a Macintosh 466 MHz G3 computer (Cupertino, CA, USA).

Scanning transmission electron microscopy

Scanning transmission electron micrographs were taken of the pumpkin pudding samples using a Jeol 6400 V scanning electron microscope (Jeol Incorporated, Peabody, MA, USA). Films of the pumpkin pudding were sputter-coated with a 20-znm coating of a gold–palladium alloy prior to microscopic examination. The accelerating voltage of the beam was 10 kV, with an aperture opening to produce an adjustable spot. The lens settings were also adjusted for the desired magnification.

Results and discussion

Rheological properties

The rheological properties of Ricetrim were compared with those of coconut cream. The effect of varying strain on the value of $G'(\omega)$ for commercial coconut cream and Ricetrim is illustrated in Fig. 1. For the commercial coconut cream, a very narrow region of linear viscoelastic behaviour was observed below strains of 0.1%. Above this strain value, $G'(\omega)$ was observed to drop sharply with increasing strain, indicating non-linear viscoelastic behaviour. For Ricetrim, the region of linear viscoelastic behaviour extended to strains of 10%. At strains above 10%, $G'(\omega)$ was observed to decrease with increasing applied strain.

The response of the commercial coconut cream sample to a thixotropic loop experiment is illustrated in Fig. 2. Two such experiments were done; the second loop was initiated immediately after the first loop had been completed. During the initial upward cycle of the first thixotropic loop, a marked region of shear-thickening was observed

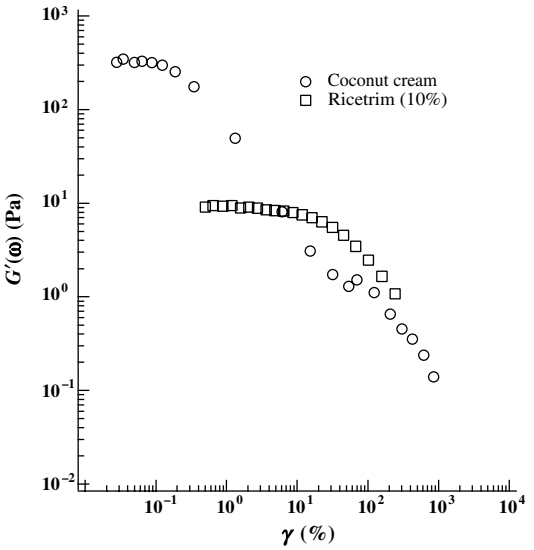

Figure 1 The effect of strain, γ, on the oscillatory shear storage modulus, $G'(\omega)$, for a commercial coconut cream and a 10% suspension of Ricetrim. The measurements were performed at a frequency of 1 s^{-1} and at 25 °C.

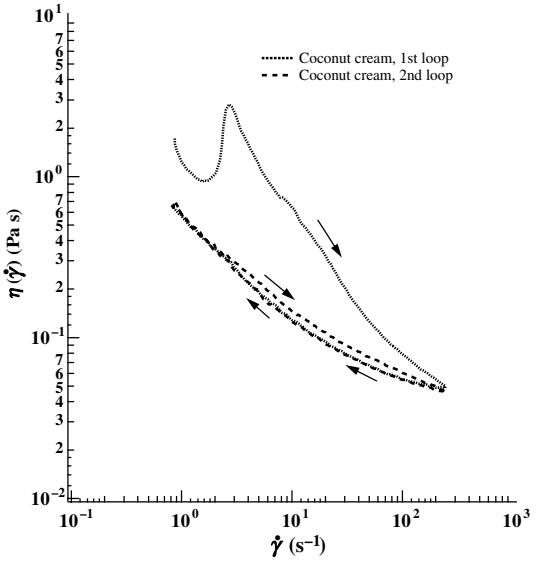

Figure 2 The response of a commercial coconut cream sample to a thixotropic loop experiment conducted at 25 °C. A shear-thickening region is clearly observed during the initial thixotropic loop experiment starting at approximately 1.7 s^{-1}. The arrows indicate the direction of the applied shear for each of the loops. η is the shear viscosity and $\dot{\gamma}$ is the shear rate.

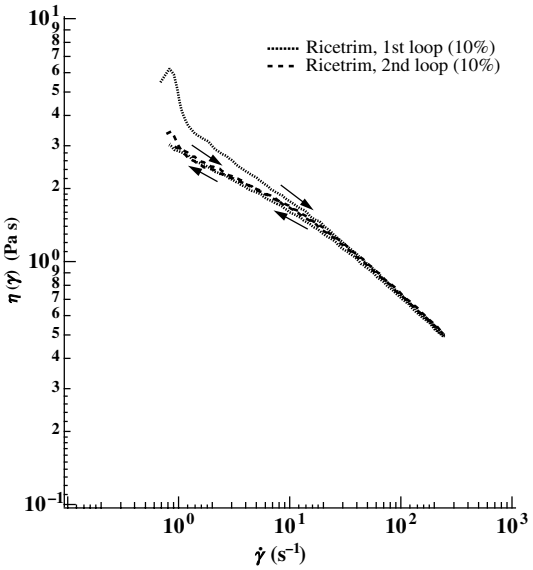

Figure 3 The response of a 10% by weight suspension of Ricetrim in de-ionized water to a thixotropic loop experiment conducted at 25 °C. The arrows indicate the direction of the applied shear for each of the loops. η is the shear viscosity and $\dot{\gamma}$ is the shear rate.

between shear rates of 1.7–2.5 s^{-1}. At shear rates above 2.5 s^{-1}, the sample exhibited shear-thinning behaviour. The viscosity at the completion of the first thixotropic loop was slightly lower than the starting viscosity. Repetition of the thixotropic loop experiment (Fig. 2) followed the viscosity versus shear rate curve that was generated during the second half of the initial experiment. These data indicate that the coconut cream sample initially possessed some internal structure or aggregation that was broken by the initial application of the shear field. Using a fresh sample of coconut cream and executing a thixotropic loop experiment starting at 250 s^{-1} and decreasing to 0.8 s^{-1} did not show any evidence of the shear-thickening behaviour shown in Fig. 2 (data not shown). This result again supports the conclusion that the applied shear field disrupted some structure or aggregation originally present in the sample.

The response of the sample, which had 10% by weight Ricetrim suspension, to the imposition of a thixotropic loop experiment is illustrated in Fig. 3. Ricetrim displayed a region which could possibly be seen as shear-thickening behaviour near 0.8–1.0 s^{-1}; however, the shear rates were near the limits of detection of the rheometer and were not regarded as reliable. At shear rates above 1 s^{-1}, the Ricetrim suspension displayed only shear-thinning behaviour. The final viscosity was slightly lower than the initial viscosity, but the difference was lower than that observed for the coconut cream sample. Repetition of the thixotropic loop experiment immediately following the completion of the first experiment gave the same viscosity versus shear rate curve that was generated during the second half of the initial experiment.

The rheological behaviours of the Ricetrim suspension and the commercial coconut cream were characterized using a power law constitutive equation, which may be expressed as

$$\eta = K\dot{\gamma}^{m-1}, \qquad (1)$$

where η is the shear viscosity, $\dot{\gamma}$ is the shear rate, K is the front factor and m is the power law exponent (Bird *et al.*, 1977). The majority of fluids exhibit pseudoplastic behaviour and have values of m between 0.15 and 0.6. Equation (1) was fitted to the data for the upward and downward parts of the initial thixotropic loop experiment using the Ricetrim suspension and the commercial coconut

Table 1 Power law model parameters for 10% by weight Ricetrim suspension and coconut cream. The values represent ±1 s.d. in the fitted parameters

Material	K (Pa s^m)	m
Ricetrim (upward cycle)	3.84 ± 0.01	0.653 ± 0.002
Ricetrim (downward cycle)	2.93 ± 0.02	0.716 ± 0.003
Coconut cream (upward cycle)	8.0 ± 0.2	−0.13 ± 0.02
Coconut cream (downward cycle)	0.553 ± 0.004	0.392 ± 0.007

cream sample. For the coconut cream sample, the model was fitted to the data in the upward cycle of the shear-thinning region after the shear-thickening regime. The results of the data fits are summarized in Table 1. It is evident from the model parameters that were fitted that the Ricetrim suspension exhibited less pronounced shear-thinning behaviour over the shear rate range that was studied than did the commercial coconut cream sample.

The response of the commercial coconut cream and the 10% Ricetrim suspension to the start up of steady-state shear is illustrated in Fig. 4. At the lowest shear rate, 0.2 s^{-1}, both the coconut cream sample and the Ricetrim suspension display a slight stress overshoot with a rapid decay to a stable plateau. At the higher shear rates, evidence for stress overshoot behaviour was not observed. Stable plateaus were obtained rapidly by both materials at shear rates of 1 and 10 s^{-1}. At an applied shear rate of 100 s^{-1}, the Ricetrim suspension exhibited a stable plateau, but the coconut cream sample appears to exhibit slight thixotropic behaviour, i.e. a gradual decrease in the shear stress growth function with time. Evidence of thixotropic behaviour for Ricetrim was not observed for the shear rates examined in this study.

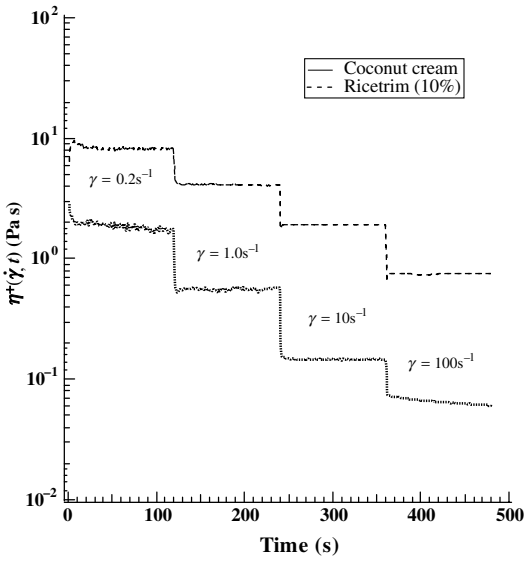

Figure 4 The effect of shear rate, $\dot{\gamma}$, on the shear stress growth functions, $\eta^+(\dot{\gamma}, t)$, for coconut cream and a 10% suspension of Ricetrim at 25 °C.

Sensory evaluations

Sensory evaluation scores for the fibre gel replacement products are shown in Table 2. At the 40% level, the texture of the cookies showed firmness with some decrease in taste performance (6.55 compared with 7.75 for the control).

Pumpkin pudding prepared at 50, 75 and 100% replacement levels with the fibre gel composite showed acceptable performance compared with the control. The 50% replacement product was statistically similar to the control especially for appearance, colour, texture and general acceptability (7.20 compared with 7.53 for the control). The performance, even at the highest replacement (100%), was well received with scores greater than 6.5. The pudding texture at 100% substitution was softer than the other puddings.

Layer cake at the 40% substitution level showed no statistical difference in taste from the control. Slight taste difference was noted at the 60% level (6.68 compared with 7.59 for the control). However, products with scores higher than 6 are considered suitable when compared with the controls. Although, the 40% substitution level product was satisfactory for colour and texture this was not so at higher substitution levels.

Dip for fried pot crust at the 40 and 60% substitution levels gave statistically lower taste scores than the control (7 and 6.91, respectively compared with 7.65 for the control). The slurry suspension became thicker when the fibre gel substitution was increased.

Taro custard at the 40% substitution level gave statistically lower taste scores than for the control (6.77 compared with 7.30 for the control). A small decrease in taste score was noted at the 60% level (6.55 compared with 7.30 for the control). However, even at 80% substitution, the taro custard

Table 2 Thai foods: sensory evaluation of products with soluble fibre gel substitution for fat*

	Appearance	Colour	Odour	Taste	Texture	Acceptability
Cookies*						
Control	7.63[a]	7.50[a]	7.78[a]	7.75[a]	7.70[a]	7.72[a]
40%	6.82[b]	6.95[b]	6.57[b]	6.55[b]	5.72[c]	5.88[b]
60%	6.47[bc]	7.03[b]	6.32[b]	6.03[c]	4.75[c]	4.85[c]
80%	6.28[c]	6.90[b]	5.95[c]	5.60[c]	3.83[d]	4.05[d]
Pumpkin pudding						
Control	7.47[a]	7.43[a]	7.65[a]	7.65[a]	7.53[a]	7.53[a]
50%	7.40[a]	7.53[a]	7.15[b]	7.22[b]	7.22[ab]	7.20[a]
75%	7.50[a]	7.25[a]	6.97[bc]	7.00[bc]	6.93[bc]	6.75[b]
100%	7.50[a]	7.22[a]	6.60[c]	6.85[c]	6.55[c]	6.55[b]
Layer cake						
Control	7.77[a]	7.75[a]	7.75[a]	7.59[a]	7.57[a]	7.70[a]
40%	6.64[b]	6.66[b]	6.77[b]	7.18[a]	7.02[b]	6.80[b]
60%	5.52[c]	5.27[c]	6.05[c]	6.68[b]	6.02[c]	6.00[c]
80%	5.43[c]	4.80[c]	5.36[d]	5.68[c]	5.18[d]	4.90[d]
Fried pot crust and dip						
Control	7.68[a]	7.44[a]	7.50[a]	7.65[a]	7.71[a]	7.74[a]
40%	7.06[b]	7.03[b]	7.03[b]	7.00[b]	6.74[b]	6.76[b]
60%	6.88[bc]	7.00[b]	6.85[bc]	6.91[b]	6.24[c]	6.44[b]
80%	6.65[c]	6.94[b]	6.15[c]	6.62[b]	5.97[c]	5.97[c]
Taro custard						
Control	6.98[a]	7.18[a]	7.43[a]	7.30[a]	7.30[a]	7.50[a]
40%	6.66[a]	7.02[a]	6.77[b]	6.77[b]	6.80[b]	6.77[b]
60%	6.73[a]	7.00[a]	6.57[c]	6.55[c]	6.48[c]	6.43[c]
80%	6.61[a]	6.93[a]	5.80[d]	6.05[d]	6.09[d]	5.75[d]
Main dish (sauté chicken curry)						
Control	8.05[a]	8.00[a]	8.00[a]	7.90[a]	8.05[a]	8.20[a]
40%	7.25[b]	7.43[b]	7.18[b]	7.20[b]	6.97[b]	7.20[b]
60%	6.72[c]	6.88[c]	6.65[c]	6.88[c]	6.30[c]	6.47[c]
80%	6.38[d]	6.60[c]	6.18[d]	6.38[d]	5.82[d]	5.95[d]

In a column, mean values followed by the same superscript are not significantly different at $P < 0.05$ by ANOVA and Duncan multiple range test.
*Prepared by blending 10% (by weight) Ricetrim soluble fibre composite in hot water and refrigerating overnight before use.

had characteristics and acceptability scores around or above 6. The texture was suitable as it contained cereal, which gave the product more moistness.

Sauté chicken curry at the 40% substitution level had a statistically lower taste scores than for the control (7.20 compared with 7.90 for the control). A small decrease in taste score was noted at the 60% level (6.88 compared with 7.90 for the control). Even at 80% substitution, the chicken curry had characteristics and acceptability scores around or higher than 6. The slurry suspension, however, became thicker when the fibre gel substitution was increased.

The Thai foods containing the fibre gels gave acceptability scores higher than 6 (Table 2) and were analysed for proximate composition and saturated fat. The composition results are given as grams per 100 g in Table 3.

Changes in saturated fat compositions

The saturated fat contents are summarized in Table 4. As pumpkin pudding, layer cake, dip for fried pot crust, taro custard and sauté chicken curry are normally made by using coconut cream as an ingredient, the saturated fat contents are substantially reduced by using fibre gel. Each product had a different amount of saturated fat depending on the percentage of fibre substitution used. For pumpkin pudding, the saturated fat was reduced from 7.7 to 0.44 g with 100% fibre gel substitution (94.3%). Layer cake had a 59.8% saturated fat reduction at 60% fibre gel substitution. At 80% fibre gel usage for the dip for fried pot crust, the saturated fat content was reduced by 75.3%. For the taro custard, its saturated fat content was reduced by 61.3% using 60% fibre gel

Table 3 Proximate compositions (grams per 100 g) of the acceptable Thai foods

Product	Moisture	Fat	Protein	Ash	Fibre	Carbohydrate	Calories
Cookies							
Control	7.4	25.4	6.3	1.2	0.54	59.16	490.5
40% fibre substitute	8.1	13.3	5.9	1.15	0.92	70.63	425.6
Pumpkin pudding							
Control	46.35	7.8	4.9	1.05	2.3	37.6	240.3
100% fibre substitute	52.2	1.8	4.0	1.1	2.7	38.2	184.8
Layer cake							
Control	37.7	13.8	2.1	0.57	0.60	45.23	313.4
60% fibre substitute	44.2	4.3	1.7	0.60	1.2	48.0	237.5
Dip for fried pot crust							
Control	55.15	17.3	9.6	1.2	3.4	13.35	247.6
80% fibre substitute	64.5	6.8	8.4	1.1	6.35	12.85	146.0
Taro custard							
Control	52.9	12.0	5.3	1.0	0.84	27.96	240.7
60% fibre substitute	58.3	8.75	5.0	0.95	1.5	25.5	200.8
Sauté chicken curry							
Control	61.4	12.6	16.3	1.4	1.0	7.3	207.9
60% fibre substitute	68.4	5.1	11.5	1.4	1.1	12.5	141.8

Table 4 Saturated fat reductions in products with soluble fibre gel substitution in Thai foods (100 g basis)

Thai foods	Saturated fat (g)	Reduction of saturated fat (%)
Cookies		
Control	25.4	
40% fibre substitute	13.3	47.8
Pumpkin pudding		
Control	7.7	
100% fibre substitute	0.44	94.3
Layer cake		
Control	9.8	
60% fibre substitute	3.9	59.8
Dip for fried pot crust		
Control	13.0	
80% fibre substitute	3.2	75.3
Taro custard		
Control	9.1	
60% fibre substitute	3.5	61.3
Sauté chicken curry		
Control	12.5	
60% fibre substitute	4.9	60.6

replacement. The sauté chicken curry showed a decrease of saturated fat of 60.6% for a 60% fibre gel substitution.

Surface evaluation using scanning transmission electron micrographs

Pumpkin pudding (Fig. 5) was used as a representative sample for an examination of the surface

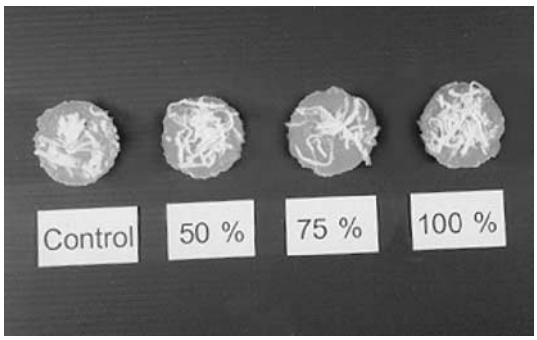

Figure 5 Photographs of the pumpkin puddings, substituting Ricetrim for coconut cream in the following proportions: 0% fibre gel, 100% coconut cream (control); 50% fibre gel, 50% coconut cream; 75% fibre gel, 25% coconut cream; and 100% fibre gel, 0% coconut cream.

structural changes found by replacing coconut cream with Ricetrim. Photographs of the control (100% coconut cream) and pumpkin puddings substituted with Ricetrim in the following proportions: 0% fibre gel, 100% coconut cream (control); 50% fibre gel, 50% coconut cream; 75% fibre gel, 25% coconut cream; and 100% fibre gel, 0% coconut cream showed little difference in visual observation. However, differences are seen in the scanning transmission electron micrographs. The surfaces of pumpkin puddings produced using either coconut cream or Ricetrim, at a magnification of 2000× are shown in Fig. 6. The surface of the pumpkin pudding produced using coconut

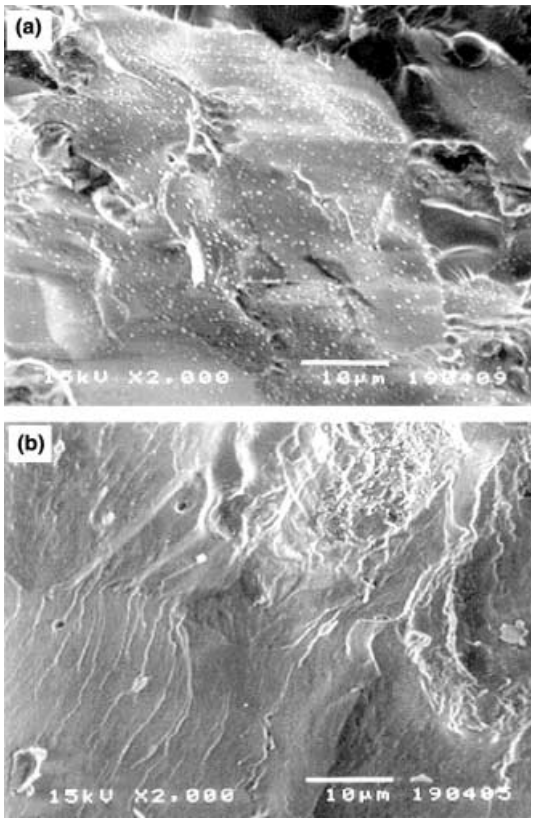

Figure 6 Scanning transmission electron micrographs of the surfaces of a pumpkin pudding sample containing (a) coconut cream (control) and (b) Ricetrim (100% substitution) at a magnification of 2000×.

cream (Fig. 6a) presented a convoluted topology. Regions in the surface and interior of the pumpkin pudding displayed large aggregates, which may have represented regions of poorly dispersed coconut cream. In contrast, the surface of the pumpkin pudding produced using Ricetrim (Fig. 6b) displayed a smooth, uniform topology without evidence of large aggregates. As both coconut cream and Ricetrim are multicomponent suspensions, the differences observed in the surface topology may indicate that Ricetrim is more finely and uniformly dispersed in the final product than is coconut cream.

Conclusions

The rheological properties of a hydrocolloidal fibre gel composite prepared from rice bran and barley flour were found to have some similarity in shear-thinning functionality to coconut cream. The rheological behaviours of the suspension and the commercial coconut cream were characterized by using a power law constitutive equation. The Ricetrim suspension exhibited less pronounced shear-thinning behaviour over the shear rate range studied than did the commercial coconut cream sample. Six Thai foods, ordinarily high in saturated fat, were found to have considerably reduced saturated fat contents after replacement with the fibre gel from Ricetrim. Using substitution levels between 40 and 100%, the saturated fat contents were reduced by 47.8, 94.3, 59.8, 75.3, 61.3 and 60.6% for cookies, pumpkin pudding, layer cake, dip for pot crust, taro custard and sauté chicken curry, respectively. The substitution of the fibre gel for saturated fat in the formulations produced some differences in the foods; however, these differences appeared to make only small reductions in the overall acceptability or suitability of the reduced fat foods.

Acknowledgments

The authors would like to acknowledge the assistance of Mr A.J. Thomas in the preparation of the Ricetrim suspensions and Dr A. Thompson for the scanning transmission electron micrographs. This work was supported by The United States Department of Agriculture.

References

Association of Official Analytical Chemists (1998). *Official Methods of Analysis*, 16th edn, 4th Revision, Vol. II, Section 32. Pp. 1–29. Gaithersburg, MD: AOAC International.

Behall, K.M., Scholfield, D.J. & Hallfrisch, J. (1997). Effect of beta-glucan level in oat fiber extracts on blood lipids in men and women. *Journal of the American College of Nutrition*, **16**, 46–51.

Bird, R.B., Armstrong, R.C. & Hassager, O. (1977). *Dynamics of Polymeric Liquids, Volume 1: Fluid Mechanics*. p. 208. New York: John Wiley and Sons.

Food and Drug Administration (1997a). Food labeling: health claims; soluble fiber from whole oats and risk of coronary heart disease. *Federal Register*, **62**, 15343–15344.

Food and Drug Administration (1997b). Food labeling: health claims; oats and coronary heart disease. *Federal Register*, **62**, 3584–3601.

deGroot, A.P., Luyken, R. & Pikaar, N.A. (1963). Cholesterol-lowering effect of rolled oats. *Lancet*, **2**, 303–304.

Inglett, G.E. (1991). *A Method of Making a Soluble Dietary Fiber Composition from Oats*. U.S. Patent Number 4,996,063. 26 February. Alexandria, VA, USA: United States Patent & Trademark Office.

Inglett, G.E. (1992). *Method of Making Soluble Dietary Fiber Compositions from Cereals*. U.S. Patent Number 5,082,673. 21 January. Alexandria, VA, USA: United States Patent & Trademark Office.

Inglett, G.E. (1993). Amylodextrins containing beta-glucan from oat flours and bran. *Journal of Food Chemistry*, **47**, 133–136.

Inglett, G.E. (1999). Nutraceuticals: the key to healthier eating. *ChemTech: Innovation in Chemistry and Technology*, **29**, 38–42.

Inglett, G.E. (2000). *Soluble Hydrocolloid Food Additives and Method of Making*. U.S. Patent Number 6,060,519. 9 May. Alexandria, VA, USA: United States Patent & Trademark Office.

Inglett, G.E. & Grisamore, S.B. (1991). Maltodextrin fat substitute lowers cholesterol. *Food Technology*, **45**, 104.

Inglett, G.E. & Newman, R.K. (1994). Oat beta-glucan-amylodextrins: preliminary preparations and biological properties. *Plant Foods for Human Nutrition*, **45**, 53–61.

Inglett, G.E., Warner, K. & Newman, R.K. (1994). Sensory and nutritional evaluations of Oatrim. *Cereal Foods World*, **39**, 755–759.

Inglett, G.E., Maneepun, S. & Vatanasuchart, N. (2000). An evaluation of hydrolyzed oat flour as a replacement for butter and coconut cream in food desserts. *Food Science and Technology International*, **6**, 457–462.

Jham, G.N., Teles, F.F.F. & Campas, L.G. (1992). Use of aqueous HCl/MeOH as esterification reagent for analysis of fatty acids derived from soybean lipids. *Journal of the American Oil Chemists Society*, **59**, 132–133.

Maneepun, S., Boonpunt, T. & Inglett, G.E. (1998a). Sensory and nutritional evaluation of co-processed NutrimX OB and soy flour in Thai dishes. p. 31. 216th American Chemical Society, Agricultural and Food Chemistry Division Abstracts.

Maneepun, S., Vatanasuchart, N. & Inglett, G.E. (1998b). NutrimX OB, a substitute for coconut cream in Thai desserts: a sensory and nutritional evaluation. p. 31. 216th American Chemical Society, Agricultural and Food Chemistry Division Abstracts.

Ripsin, C.M., Keenan, J.M. & Jacobs, D.R. (1992). Oat products and lipid lowering. *Journal of the American Medical Association*, **267**, 3317–3325.

